SIMPLE DIRECTIONS FOR THE DETERMINATION OF THE COMMON MINERALS AND ROCKS

A LABORATORY COURSE IN GENERAL GEOLOGY

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INCLUDING A METHOD OF PREPARING TOPOGRAPHICAL MAPS WITH USE OF SPECIAL APPARATUS AND EXERCISES IN THE PREPARATION AND INTERPRETATION OF GEOLOGICAL MAPS UPON THE BASIS OF SPECIALLY DESIGNED LABORATORY TABLES AND ATTACHED MODELS

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PREFACE

This booklet is the reprint of a portion of the matter appended to "Earth Features and their Meaning" (Macmillan, 1912), and is intended to serve as a laboratory guide in a cultural course in general geology. In order to present clearly the method of making use of the special geological models, it has been found necessary to incorporate a few pages from the body of the work. There may be some who would make use of this guide who are not connected with large educational institutions and who do not have access to a geological or mineralogical laboratory. To aid them in becoming familiar with the common minerals and rocks, as well as to supply universities and colleges with the necessary illustrative material, Ward's Natural Science Establishment of Rochester, New York, has prepared and now offers for sale a "Collection of Minerals and Rocks for General Geology." The special apparatus for the study of topographic map methods is sold by Eberbach and Son of Ann Arbor, Michigan; who also are prepared to furnish upon order improved special tables with their necessary equipment for practice in the methods of preparing geological maps.

Note. — Some who use this guide in connection with a study of "Earth Features and their Meaning" may for convenience prefer to have the laboratory guide in separate form, and for this reason the numbers which refer to pages in the body of the text have not been eliminated.

CONTENTS

SIMPLE DIRECTIONS FOR THE DETERMINATION OF THE COMMON MINERALS AND ROCKS

APPENDIX A

THE QUICK DETERMINATION OF THE COMMON MINERALS

Before one may gain a knowledge of rocks or the architecture of their arrangement within the earth's crust, it is quite essential that some familiarity should be acquired with the appearance and properties of the commonest minerals, and particularly those which enter as essential constituents into the more abundant rocks. To be a competent mineralogist, one must have a rather extended knowledge both of inorganic chemistry and of the science of crystallography, which, fascinating as it is to study, involves some technical knowledge of mathematics and much laboratory experience. Though necessary to any one who contemplates making a career as a geologist, this special study is not essential to a cultural course like the present one. The attempt will here be made to bring together a body of fact, from the study of which the student may quickly learn to recognize the commonest minerals in their usual varieties. The tests he is to apply are mainly physical, and in place of an elaborate discussion of crystal symmetry, pictures only can be supplied.

To the beginner the usual textbook of mineralogy is difficult to read intelligently, for the reason that for each mineral species it sets before him a catalogue of each physical property in its turn, with little indication of those data which in the individual case have special diagnostic value. None the less, however, the student is advised to consider the several properties of each mineral in a definite order, and the following may serve as well as any: crystal or other form, cleavage, fracture, luster, color, streak, transparency, tenacity, hardness, magnetism, and specific gravity. In endeavoring to connect the specific values of these properties with individual mineral species, the chemical composition and the manner of occurrence are not to be forgotten. It is well for the student to be supplied with a small pocket lens and with a pocket knife the blade of which has been magnetized.

Crystal form. — Some mineral species generally occur in more or less definite crystals — are bounded by definite plane surfaces developed when the mineral was formed; others in groups of interfering crystals or aggregates, in which case the mineral is said to be crystalline; while still others are rarely found crystallized at all. Thus in a given case crystal form may, or may not, be important for the diagnosis of the substance. If

a mineral species is usually to be found in crystals, the student should be aware of the fact, and if possible should have a mental picture of the common crystal shape or shapes. Without an extended knowledge of crystallography, this must be supplied him by drawings. Since crystals of most species are apt to be distorted, owing to the fact that some planes within the same group appear upon the crystal with a larger development than others, it is convenient to remember that markings, such as lines or etchings upon the crystal faces, are the same throughout the same group of planes, and in the text figures such groups of planes are indicated by the use of a common letter. For crystalline aggregates such terms as fibrous, radiating, massive, or granular have their usual meanings.

Cleavage. — It is characteristic of most crystals that they break or *cleave* along certain directions so as to leave plane or nearly plane surfaces, and the luster of the cleaved surface measures the perfection of the cleavage property. It is important always to note how many such directions of cleavage are present, and, roughly at least, at what angles they intersect — whether they are perpendicular to each other or inclined at some other angle. Further, it should be noted whether a given cleavage is *perfect*, that is, easy, which will be indicated by the thinness of the plates which can be secured. An extremely perfect cleavage is possessed by the mineral mica, whose plates are thinner than the thinnest paper. In the case of imperfect or interrupted cleavage, the fracture surfaces are not plane throughout but interrupted, the surface "jumping" from one plane to a neighboring parallel one. It is especially important to note whether, in the case of several cleavages possessed by a crystal, all have the same degree of perfection, or whether they exhibit differences.

Fracture. — In minerals with poorly developed cleavage, the fracture surface is described as *fracture*. Fracture is thus perfect in proportion as cleavage is imperfect. The fracture is described as conchoidal when it shows waving spherical surfaces like broken glass. For fine aggregates the fracture is described as even, uneven, earthy, etc., names which are generally intelligible.

Luster. — This term is applied especially to the manner in which light is reflected from mineral surfaces. The most important distinction is made between those minerals which have a *metallic* luster and those which have not, the former being always opaque. Other characteristic lusters are adamantine (like oiled glass), vitreous (glassy), resinous, waxy, etc.

Color. — For minerals which possess metallic luster the color is always practically the same, and hence it becomes a valuable diagnostic property. Of minerals which have nonmetallic luster, the color may be always

the same and hence characteristic, but in the case of many minerals it ranges between wide limits and sometimes runs almost the entire gamut of hues, yet without appreciable changes in the chemical composition of the mineral.

Streak. — This term is applied to the color of the mineral powder, and is usually fairly constant, even when the surface color of different specimens may vary within wide limits. In the case of fairly soft minerals the streak is best examined by making a mark on a piece of unglazed porcelain (streak stone).

Transparency (diaphaneity). — The terms "transparent," "translucent," "subtranslucent," and "opaque" are used to describe decreasing grades of permeability by light rays. Through transparent bodies print may be read, while translucent bodies allow the light to be transmitted in considerable quantity through them, though without rendering the image of objects.

Tenacity. — This comprehensive term includes such properties as brittleness, flexibility, elasticity, malleability, etc.

Hardness. — Quite erroneous notions are held concerning the meaning of this very common word, which properly implies a resistance offered to abrasion. It is one of the most valuable properties for the quick determination of minerals, since minerals range from diamond upon the one hand — the hardest of substances — to talc and graphite, which are so soft as to be deeply scratched by the thumb nail. For practical purposes it is sufficient to make use of a rough scale of hardness made up from common or well-known minerals. If we exclude the gem minerals, this scale need include but seven numbers, which are: talc, 1; gypsum, 2; calcite, 3; fluor spar, 4; apatite, 5; feldspar, 6; and quartz, 7. A given mineral is softer than a mineral in the scale when it can be visibly scratched by a scale mineral, but will not leave a scratch when the conditions are reversed. If each will scratch the other with equal readiness, the two minerals have the same hardness.

Since it may often be desirable to test mineral hardness when no scale is at hand, the following substitutes may be made use of: 1, greasy feel and easily scratched by the thumb nail; 2, takes a scratch from the thumb nail, but much less readily; 3, scratched by a copper coin and very easily by a pocket knife; 4, scratched without difficulty by a knife; 5, scratched with difficulty by a knife, but easily by window glass; 6, scratched by window glass; 7, scratches window glass with readiness, but a grain of sand may be substituted to represent quartz in the scale.

Magnetism. — Though nearly all minerals which contain important quantities of the elements iron, cobalt, or nickel may be attracted to a strong electromagnet, there are but two common minerals, and these

of widely different appearance, whose powder is lifted by a common magnet. Others are, however, lifted after strong heating in the air (*ignition*), and this is a valuable test.

Specific gravity. — Rough tests of relative weight, or specific gravity, may be made by lifting fair-sized specimens in the hand. Better determinations require the use of a spring balance.

Treatment with acid. — The carbonate minerals react with warm and dilute mineral acid so as to give a boiling effect (effervescence), since carbonic acid gas escapes into the air in the process.

PROPERTIES OF THE COMMON MINERALS

The more important common minerals fall into two classes according as they have large economic importance as ores, or enter in an important way into the composition of rocks.

I. The Minerals of Economic Importance

Hematite. — The sesquioxide of iron, Fe_2O_3, and by far the most important ore of iron. Rarely in good crystals, but sometimes in thin opaque scales bearing some resemblance to mica and known as micaceous or specular iron ore. At other times in nodules built up from radial needles (needle ore); in hard masses mixed with fine quartz grains (hard hematite); or in soft reddish brown earth (soft hematite). Color, black to cherry red. The powdered mineral always cherry red or reddish brown, and easily lifted by the magnet after ignition. Hardness 5.5–6.5; specific gravity 5.

Magnetite. — The magnetic oxide of iron, Fe_3O_4, often in crystals like Fig. 486, 1–2. Black and opaque with a metallic luster. Streak black. Lifted by a magnet and sometimes itself capable of lifting filings of soft iron (lodestone). Hardness 5.5–6.5. Specific gravity 5.

Limonite. — The most abundant and most valuable of the hydrated iron ores, $2\ Fe_2O_3 \cdot 3\ H_2O$. Chemical composition the same as iron rust, with which in the earthy form it is identical. Never in crystals, but often in mammillary or rounded pendant forms resembling icicles, or sometimes clusters of grapes. Its yellow (rust) streak is its best diagnostic property. Ignited it gives off water and becomes magnetic. The streak and its notably lower specific gravity distinguish it from certain forms of hematite which it outwardly resembles. Hardness 5–5.5. Specific gravity 3.6–4.

Pyrite, iron pyrites, or "fool's gold." — The sulphide of iron, FeS_2. The most widely distributed sulphide mineral and now a chief source of

the great chemical reagent, sulphuric acid or vitriol. Often, but not always, in crystals (Fig. 486, 3–5) which have peculiar striæ upon their faces. At other times the mineral is found massive or in radiated needles. Bright metallic luster with the color of new brass, though often tarnished or altered upon the surface to limonite. Hard and brittle, and so distinguished from gold, which is soft and malleable and of the color of the paler old brass (which contained a larger percentage of zinc). Gold is, further, about four times as heavy as pyrite. Hardness 6–6.5. Specific gravity 5.

Chalcopyrite, copper pyrites. — A mixed sulphide of copper and iron. If in crystals, like Fig. 486, 6; otherwise massive or compact. Luster metallic. Color orange-yellow, often with local blue and green iridescence like a pigeon's throat. Distinguished from pyrite by the deeper color and lower hardness, and from gold, particularly, by its brittleness and lower specific gravity. Hardness 3.5–4. Specific gravity 4.

Galenite, galena. — Sulphide of lead, PbS. The chief ore of lead, and, from admixture of a silver mineral, of silver as well. Usually found in crystals (Fig. 486, 7). Always cleaves into blocks bounded by six very perfect rectangular faces which, when freshly broken, show a bright silvery luster and quickly tarnish to a peculiarly "leaden" surface. Very heavy. Color and streak lead-gray. Hardness 2.5. Specific gravity 7.5.

Sphalerite, zinc blende. — Sulphide of zinc, ZnS, usually with considerable admixture of sulphide of iron. The great ore of zinc. Not infrequently in crystals (Fig. 486, 8–9), but more often in cleavable crystalline aggregates. The cleavage in fine aggregates is sometimes difficult to make out, but in coarse-grained masses it is seen to be equally and highly perfect in six different directions, so that a symmetrical twelve-faced form may sometimes be broken out (dodecahedron). Luster like that of rosin (rosin jack), though when with large iron admixture the color may approach black (black jack). The lighter colored varieties are translucent. Hardness 3.5–4. Specific gravity 4.

Malachite. — Hydrated (basic) copper carbonate. The green copper ore and the common surface alteration product of other copper minerals. Usually has a microscopic structure made up of fine needle-like crystals, but generally massive in various imitative shapes not unlike those of the iron ores. Sometimes earthy. Its color is bright green, and it is usually found in association with other characteristic copper ores, such as chalcopyrite and azurite. When relatively pure and in large masses, it is a beautiful ornamental stone. Effervesces with acid. Hardness 3.5–4. Specific gravity 4.

Azurite. — Hydrated (basic) copper carbonate, less hydrated than malachite, and known as the blue carbonate of copper. Generally in

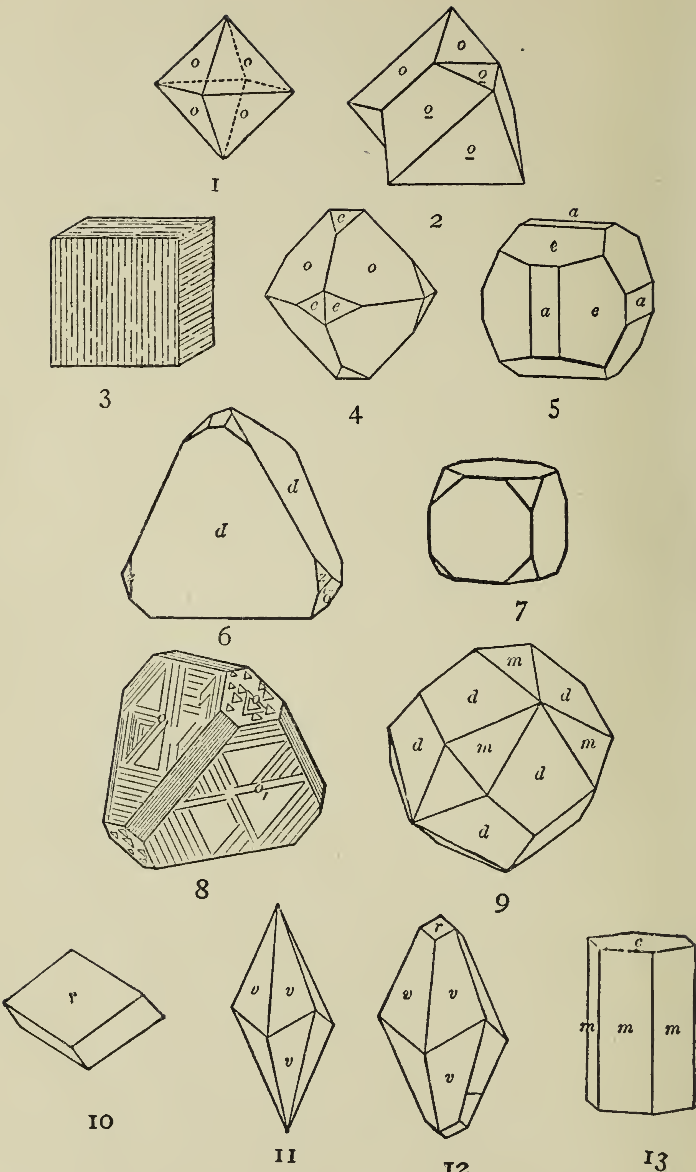


Fig. 486. — Forms of Crystals: 1–2, magnetite; 3–5, pyrite; 6, chalcopyrite; 7, galenite; 8–9, sphalerite; 10–13, calcite.

very minute and quite complex crystals, but also in imitative shapes similar to those of malachite, and at other times earthy. Slightly lighter in weight than malachite, from which it is easily distinguished, as from most other minerals, by its bright azure blue color and its somewhat lighter blue streak. Effervesces with nitric acid. Hardness 3.5–4. Specific gravity 3.7–3.8.

Calcite. — Calcium carbonate, $CaCO_3$. Almost always in crystals (Fig. 486, 10-13), or in confused crystal aggregates, though rarely fibrous or dull and earthy. Some of the forms of the crystals are described as "dog-tooth spar," others as "nail-head spar," while still others are modified hexagonal prisms. There is a beautifully perfect cleavage of the mineral along three directions which make angles of about 105° with each other, so that under the hammer the substance breaks into blocks which are shaped like the crystal of Fig. 486, 10. Usually white or gray, but occasionally faintly tinted. Streak white. Effervesces with cold and dilute mineral acids. An associate of many ores and the chief mineral of limestone. A similar mineral — dolomite — contains in addition magnesium carbonate, has simpler crystals (like the drawing of Fig. 486, 10, but often with rounded faces), and effervesces only when the acid is warmed. Hardness 3. Specific gravity 2.7.

Gypsum. — Hydrated calcium sulphate, $CaSO_4 . 2\,H_2O$, and the source of plaster of Paris. Often in simple crystals (Fig. 487, 1) or else "swallow tail," like Fig. 487, 2, in which case the mineral is generally either transparent or translucent and is described as selenite. Such crystals show a cleavage approaching in perfection that of the micas, but, unlike the mica laminæ, those produced by cleavage in gypsum though flexible are not elastic. There are also fibrous forms of gypsum (satin spar), a fine-grained form (alabaster), and the impure earthy form (rock gypsum). Very soft, light in weight, and difficultly fusible. Color usually white, gray, or pale yellow. Hardness 2. Specific gravity 2.3.

Copper glance. — A sulphide of copper, Cu_2S. Not usually well crystallized, but generally massive and associated or variously admixed with other copper ores such as chalcopyrite, malachite, etc. Fracture conchoidal, luster metallic, color and streak blackish lead-gray, though often tarnished blue or green from surface alterations to the copper carbonates. Softer and heavier than chalcopyrite. Blowpipe or chemical tests are necessary for its identification. Hardness 2.5–3. Specific gravity 5.5–5.8.

Cerussite. — The white or carbonate lead ore, $PbCO_3$, and an important ore of silver as well. Often in crystals of considerable complexity, though Fig. 487, 3–4, shows some common shapes. Often granular, massive, or earthy (gray carbonate ore). Very brittle and with conchoidal fracture. The luster is adamantine or like that of oiled glass. Color generally

white or gray. Very heavy, the heaviest of light colored and nonmetallic minerals. Dissolves in nitric acid with effervescence. Hardness 3–3.5. Specific gravity 6.5.

Siderite. — The carbonate or "spathic" ore of iron, $FeCO_3$. Either in crystals resembling in form Fig. 486, 10, but with rounded faces, or cleavable massive to finely granular and earthy. The crystalline varieties cleave easily into smaller blocks of the same form as those of calcite. Color usually gray or brown and streak white. On strongly igniting, the white powder becomes black and magnetic. Lighter in both color and weight than the other iron ores, and unlike them siderite effervesces with acid. Distinguished from calcite by its higher specific gravity and its change upon being ignited. Hardness 3.5–4. Specific gravity 3.9.

Smithsonite. — Carbonate of zinc, $ZnCO_3$, and an important ore of that metal. Seldom found in crystals except as a replacement of calcite crystals, in which case it shows the forms characteristic of the latter mineral. Usually kidney-shaped, stalactitic, or else in incrustations upon other minerals. Sometimes granular or earthy. Brittle. Luster vitreous, color white or greenish gray, though often stained yellow with iron rust. Streak white except when the mineral is stained with iron. Effervesces with warm acid. Hardness 5. Specific gravity 4.4.

Pyrolusite. — Black oxide of manganese, MnO_2, though generally impure from admixture with other manganese oxides. Usually in intricate aggregates which may be columnar, fibrous, mammillary, earthy, etc. Opaque, with color and streak both black. Soft and easily soils the fingers. With hydrochloric acid gives off the choking fumes of chlorine. Hardness 2–2.5. Specific gravity 4.8.

II. The Minerals important as Rock Makers

These minerals are in most cases complex silicates of one or more of a certain number of metals such as aluminium, calcium, magnesium, iron, sodium, potassium, or hydroxyl (OH). For their identification an examination of the physical properties is usually sufficient, whereas of the typical ore minerals already considered, additional chemical tests may be necessary.

Feldspars. — A group of similar alumino-silicates of potassium, sodium, and calcium. The most important of all rock-making minerals. Although with wide variation in chemical composition, the feldspars are yet broadly divided into two classes; the one striated, and the other an unstriated potash or orthoclase variety. The pocket lens is usually necessary in order to make out the striations upon the crystal or cleavage surfaces. When formed in veins, feldspar appears in crystals (Fig. 487, 5–6), but as a rock constituent the mutual interference of crystals prevents the development

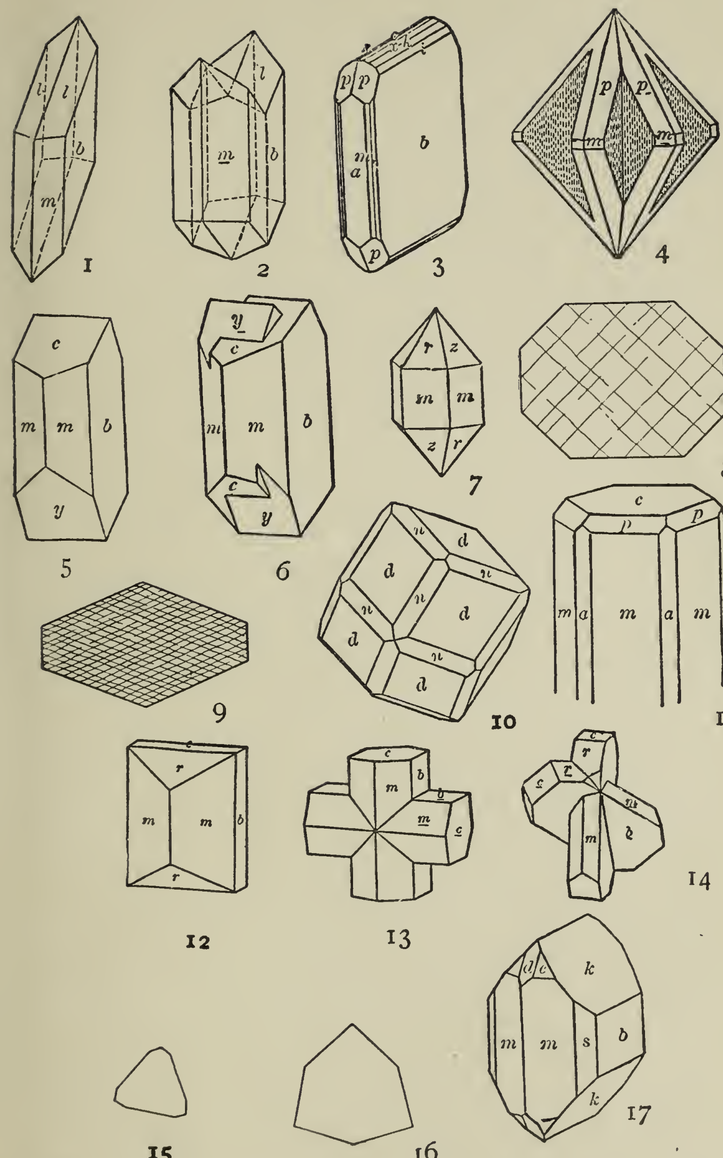


Fig. 487. — Forms of Crystals: 1–2, gypsum; 3–4, cerussite; 5–6, feldspar; 7, quartz; 8, pyroxene (cross section); 9, hornblende (cross section); 10, garnet; 11, nephelite; 12–14, staurolite; 15–16, tourmaline (cross sections); 17, olivine.

of bounding faces. Two cleavage directions, nearly or quite perpendicular to each other, are notably different in their perfection. Hard enough to scratch glass, but easily scratched by sand. Color pink (usually orthoclase or microline), white (often albite) to gray. Sometimes with beautiful "pigeon's throat" effect of iridescence (labradorite). Low specific gravity. Hardness 6. Specific gravity 2.5–2.8.

Quartz. — Oxide of silicon or silica, SiO_2. Both an important vein mineral associated with the ores and a rock maker. In the former case particularly, often in crystals of notably simple forms (Fig. 487, 7). Few minerals which are not gems are so hard. Remarkable freedom from cleavage so that the mineral breaks much like window glass — conchoidal fracture. Wide range in both transparency and color. Transparent and colorless crystalline variety (rock crystal), brown translucent (smoky quartz), turbid white (milky quartz), and various colored varieties (carnelian, jasper, etc.). Insoluble in acids and infusible. Hardness 7. Specific gravity 2.6.

Micas. — Like the feldspars a group of complex silicates, but here chiefly of potassium, magnesium, iron, and hydroxyl. Abundant as rock makers, the micas are all characterized by the thinnest and toughest of elastic cleavage plates, such as are generally known as isinglass. When a needle is driven sharply through a thin scale of mica, a six-rayed puncture star forms about the needle point. The darker common variety of mica is rich in iron and magnesium and is called biotite, and the lighter colored alkaline variety, muscovite. Hardness 2.5–3.1. Specific gravity 2.7–3.1.

Chlorite. — Generally an intricate mixture of more or less similar microscopic crystals having varying and rather complex chemical compositions and related to the micas, but all characterized by a peculiar leaf green color. These minerals are a common product of hydration weathering in rocks which are rich in magnesium and iron — especially those that contain biotite, pyroxene, or hornblende (see below). Hardness 1–2.5. Specific gravity 2.5–3.

Pyroxenes. — An important group of related rock-making minerals all of which are silicates of the bases magnesium, calcium, aluminium, iron, and manganese. Quite generally developed either in columnar or needle-like crystals which are uniformly shaped in cross section like Fig. 487, 8. Two rather imperfect cleavages are directed parallel to the longer axis of the crystal and nearly at right angles to each other. The colors of all but the lime varieties are dark and generally green, dark brown, bronze, or black. The lime varieties are white, gray, or pale green. A dark colored and common iron variety is known as augite. Streak generally either white or lightly tinted. Hardness 5–6. Specific gravity 3.2–3.6.

Amphiboles. — A group of minerals of the same chemical composition as the pyroxenes, with which also in most physical properties they agree. The principal distinction is found in the shape of the cross section and in the cleavage (Fig. 487, 9). Whereas the cross sections of pyroxenes are generally eight sided, those of the amphiboles have six sides, and whereas the cleavage directions of pyroxenes are nearly at right angles to each other (87°), the similar but much more perfect cleavage directions of the amphiboles are inclined at an obtuse angle ($124\frac{1}{2}°$). Owing to the obliquity of the amphibole cleavage, fractured surfaces of the mineral appear splintery, which is not in the same measure true of the pyroxenes. A fibrous variety of amphibole, and occasionally other varieties of the mineral, is a not uncommon product of weathering of pyroxenes. Other physical properties of the amphiboles are in the main almost identical with those of the pyroxenes. The common variety is hornblende.

Garnet. — Complex alumino-silicates or ferro-silicates of calcium, magnesium, iron, or manganese, or several of these combined. Nearly always in crystals, and usually found in mica schist (see below). The crystals usually have twelve similar faces, each a lozenge (dodecahedron), or else twenty-four similar faces, or the two forms combined (Fig. 487, 10). Brittle. From any but the gem minerals garnet is easily distinguished by its hardness, which in different varieties ranges from somewhat below to somewhat above that of quartz. The luster is vitreous, and the color runs the gamut of reds, browns, and greens, but with the common hue dark red to black. Streak white. Hardness 6.5–7.5. Specific gravity 3.1–4.3.

Nephelite (nephelene). — An alumino-silicate of sodium and potassium. In certain special provinces this mineral is developed in abundance as an essential constituent of igneous rocks, but elsewhere practically unknown. The rare crystals are hexagonal prisms (Fig. 487, 11), but the mineral is most easily determined by its general resemblance to feldspar, but with the differences of cleavage, luster, and reaction with acid. Whereas the feldspars have two cleavages, either nearly or quite perpendicular to each other and of different degrees of perfection, nephelite has three equal cleavages inclined 60° and 120° to each other and of less perfection than either feldspar cleavage. The luster of nephelite is perhaps the best clew to its identity, since this is greasy and simulated by but few minerals. The fine powder of the mineral treated for some time with strong hydrochloric acid forms a perfect jelly of silicic acid, whereas the feldspars do not. Though itself gray or white and unobtrusive, nephelite is usually associated with brightly colored minerals, which are often the first clew to its presence in a rock. Hardness 5.5–6. Specific gravity 2.5–2.6.

Talc (soapstone). — A silicate of magnesium and hydroxyl which is an important alteration product through weathering of certain pyroxene rocks especially. Usually a foliated mass, this product is occasionally fibrous or even granular. Talc is one of the softest of minerals, having a greasy feel and being easily scratched with the thumb nail. The luster of the foliated varieties is apt to be pearly, and the color apple-green to white, though sometimes stained brown from oxide of iron. The streak of the mineral is white except when stained by iron. Although the rocks which are composed mainly of talc (soapstone) are exceedingly soft, they are very tough and remarkably resistant. Hardness 1–1.5. Specific gravity 2.7–2.8.

Serpentine. — Like talc, serpentine is a silicate of magnesium and hydroxyl, and an important product of the breaking down of magnesium minerals in the process of weathering. The mineral is usually found as a fine web of microscopic needlelike fibers, and is best roughly diagnosed by its color and its associated minerals. Like talc it is usually developed within those igneous rocks from which feldspar is lacking, but where either pyroxene or olivine is found in abundance or was previous to alteration. The characteristic color of serpentine is leek-green. The rock largely composed of serpentine is called by the same name, and being exceedingly tough and unchanging is, in spite of its softness, a valuable building and ornamental stone. A red magnesium garnet is apt to be associated with such serpentine masses. Hardness 2.5–4, because of impurities. Specific gravity 2.5–2.6.

Staurolite. — A silicate of aluminium, iron, and hydroxyl. Found in metamorphic rocks usually in association with garnet. Always in crystals bounded by simple forms generally crossed, as shown in Fig. 487, 12–14. The color is dark reddish brown, and the streak is colorless to grayish. The hardness is exceptional and higher than that of quartz. Hardness 7–7.5. Specific gravity 3.6–3.7.

Tourmaline. — An exceptionally complex silicate of boron and aluminium as well as iron, magnesium, and the alkalies. Found in metamorphic rocks and always crystallized. The crystals are columns or needles whose cross section is the best guide to their identity, since this is a modified triangle unlike that of any other mineral (Fig. 487, 15–16). Additional diagnostic properties are the characteristic striations which run lengthwise of the crystals upon prism faces, and the lack of any cleavage (difference from hornblende). The hardness is also a valuable property, since this is greater than that of quartz. The mineral is brittle and the fracture subconchoidal. The range in color is as great as, or greater than, that of garnet, though the common forms are jet black. Streak uncolored. Hardness 7–7.5. Specific gravity 3–3.2.

Olivine. — A silicate of magnesium and iron and a rock-making mineral found only in those igneous rocks which have little or no feldspar. It easily suffers alteration by weathering and passes into serpentine, and in fact is seldom found except when at least partially altered to the fibrous webs of that mineral. The form of the unaltered crystals within the rocks is shown in Fig. 487, 17, and, cut in sections, the mineral appears in more or less elongated hexagons. The hardness of the unaltered mineral is about that of quartz. It has rather imperfect cleavages in two rectangular directions, and is usually translucent, with a vitreous luster and a color which is olive-green when not stained brown by oxide of iron. Streak uncolored. Hardness 6.5–7. Specific gravity 3.2–3.3.

APPENDIX B

SHORT DESCRIPTIONS OF SOME COMMON ROCKS

In Chapter IV[1] the classification and the structure of rocks have been briefly discussed. Below are added brief descriptions of the more important common rocks. For rocks as for minerals it is, however, essential that a collection of well-chosen specimens be studied for purposes of comparison. A small pocket lens is a valuable aid in making out the component minerals and the textures of the finer grained rocks.

1. Intrusive Rocks

Granite. — Of granitic texture, though sometimes porphyritic as well. The most abundant mineral constituent is a pink or white feldspar, usually without visible striations, with which there is usually in subordinate quantity a white striated feldspar. Next in importance to the feldspar is quartz, which because of its lack of cleavage shows a peculiar gray surface resembling wet sugar. In addition to feldspar and quartz there is generally, though not universally, a dark colored mineral, either mica or hornblende. The mica is usually biotite, though often associated with muscovite.

Syenite. — Like granite, but without quartz, with more striated feldspar, and generally also the rock has a darker average tint. While biotite is the commonest dark colored constituent of granite, hornblende is more apt to take its place in syenite. Less common than granite, to which it is closely related in origin and in composition.

Gabbro. — A dark colored rock of granitic texture composed of striated feldspar with broad cleavage surfaces and usually an abundance of pyroxene. In contrast to the feldspars of granite, those of gabbroes are often dull and colored grayish yellow or greenish. The pyroxene is often in part changed to fibrous amphibole. Magnetite may be an abundant accessory mineral.

Diabase. — In color dark like gabbro, and of similar constitution. In diabase, however, the feldspar crystals, instead of being broad and of irregularly interrupted outline, are relatively long ("lath-shaped"), and the pyroxene acts as a filler of the residual space between them.

Peridotite. — A heavy and dark colored rock of granitic texture which is nearly or quite devoid of feldspar but contains olivine. When altered,

[1] "Earth Features," etc., The Macmillan Co., 1912.

as it generally is, it is largely a mass of serpentine, talc, and chlorite, surrounding cores, it may be, of still unaltered pyroxene and olivine. Magnetite is an abundant constituent, and a red garnet is apt to be present.

2. Extrusive Rocks

Obsidian. — A rock glass rich in silica. It is usually black and breaks with a perfect conchoidal fracture. It often passes over through insensible gradations into pumice, which differs only in its vesicular structure. As regards chemical composition, obsidian and pumice are not notably different from rhyolite (below).

Rhyolite. — A light colored rock of porphyritic texture, often also with fluxion or spherulitic textures, or both combined. The porphyritic appearance is given the rock by large crystals of a glassy, unstriated feldspar and crystals of quartz. Rhyolite is a very siliceous lava containing rather more silica than granite, to which of the intrusive rocks it is most closely related, and from which it differs in its texture and in the manner of its occurrence in nature. Whereas granite is found in great batholites, laccolites, and bysmalites, and consolidated in most cases beneath the earth's surface, rhyolite generally occurs in sheets, flows, or dikes, and consolidated either above or in fissures near to the surface.

Trachyte. — Similar to rhyolite, but usually with a peculiar gray aspect from the greater abundance of feldspar crystals. The rock is less siliceous than rhyolite, contains no quartz crystals, and approaches a feldspar in its average composition.

Andesite. — Similar to rhyolite in appearance and in origin, but more basic and correspondingly dark in color. The porphyritic crystals are of lath-shaped, striated feldspar, with which are associated crystals of either biotite or hornblende or both. A fluxion texture is particularly characteristic of this type of extrusive rock.

Basalt. — A dark colored or black basic rock of porphyritic texture which differs but little from diabase. It may show under the lens fine lath-shaped crystals of striated feldspar associated with crystals of augite, but more frequently the rock is dense and without visible mineral constituents. It is particularly likely to occur divided up into columns six inches to a foot in diameter and known as basaltic columns. Especially fine examples are known from the Giant's Causeway and other localities in the western British Isles.

3. Sedimentary Rocks of Mechanical Origin

Conglomerate ("pudding stone"). — A rock made up from pebbles which are cemented together with sand and finer materials. The pebbles are usually worn by work of the waves upon a shore, and may vary in

size from a pea to large bowlders. They may consist of almost any hard mineral or rock, though the sand about them is largely quartz.

Sandstone. — A rock composed of sand cemented together either by calcareous, siliceous, or ferruginous materials. Sandstones are described as friable when their surface grains are easily rubbed off, or as compact when they are more firmly cemented. Sandstones are often distinctly banded and are sometimes variously stained with oxide of iron. Those sandstones which have been formed upon a seacoast are known as marine sandstones, while those derived from accumulations collected by the wind in deserts are distinguished as continental deposits. Sandstones form much thicker formations than conglomerates, the latter usually constituting a basal layer only of the sandstone formation (basal conglomerate).

Shale. — A consolidated mud stone which is probably the most abundant rock formation. In large part clay admixed in varying proportions with extremely fine sandy grains.

4. Sedimentary Rocks of Chemical Precipitation

Calcareous tufa (travertine). — Not to be confused with tuff, which is a fragmental extrusive or volcanic rock. Calcareous tufa is formed when waters which contain carbonic acid gas and lime carbonate in solution, give off the gas and with it the power to hold the lime in solution. Such a liberation of the gas may occur when the stream is dashed into spray above a cascade, and the lime is then deposited about the site of the falls. Travertine is generally porous and formed of more or less concentric layers or incrustations. A remarkable illustration is furnished by the travertine deposits of Tivoli, and other localities near Rome, since here the material supplies a valuable building stone.

Oolitic limestone (oolite). — This rock is made up of spherical nodules and so has the appearance of fish roe. Broken apart, grains may reveal in the center a core of siliceous sand about which carbonate of lime has been deposited in concentric layers. This type of limestone assumes large importance in the Jurassic formation, which in England is sometimes called the Great Oolite. Replaced by oxide of iron, oolitic limestone constitutes an important ore of iron (Clinton or oolitic iron ore).

5. Sedimentary Rocks of Organic Origin

Limestone. — A generally white or gray rock composed of carbonate of lime with varying proportions of clay, silica, and other impurities. The lime carbonate is usually derived from the hard parts of marine organisms, and the argillaceous and siliceous impurities from the finer land-derived sediments which descend with them to the bottom.

Dolomite (dolomitic or magnesium limestone). — Differs from limestone in containing varying proportions of the mineral dolomite (*ante*, p. 455), which is made up of equal parts of calcium and magnesium carbonates. Difficult to distinguish from limestone unless a chemical test is made for magnesium, though it may be said in general that dolomite is less soluble in cold mineral acids.

Peat. — An accumulation of decomposed vegetable matter within small lakes and in lagoons separated from larger ones (*ante*, p. 429). Peat represents the first stage in the formation of coal from vegetable matter, and differs from the coals by its larger proportion of contained water. Because of this water its fuel value is correspondingly small. It is usually dark brown or black and reveals something of the structure of the plants out of which it was formed.

6. Metamorphic Rocks

Gneiss. — A generally more or less banded (gneissic) metamorphic rock with a mineral constitution similar to granite, and often developed by metamorphic processes from that rock. It may at other times, by processes not essentially different, be derived from sedimentary formations. It usually contains as important constituents unstriated feldspar and quartz, but in addition it may include a striated feldspar, biotite, muscovite, or hornblende, or several of these combined. In proportion as mica or hornblende is abundant, it has a marked banded texture, but it differs from mica schist (see below) not only in the presence of its feldspar, but in the smaller proportion of mica. Biotite gneiss, hornblende gneiss, etc., are terms used to designate varieties in which one or the other of the dark colored constituents predominate.

Mica schist. — A metamorphic rock without feldspar and mainly composed of quartz and light colored mica (muscovite). The abundant mica lends to the rock its characteristic schistose texture, which differs from the usual gneissic texture. In some cases the mica is wrapped about the grains of quartz, but at other times it forms a series of almost continuous membranes separating layers of quartz.

Sericite schist. — A variety of schist which is characterized by an abundance of a peculiar silvery mica rich in the element group hydroxyl. The mica scales are often miscroscopic and wrought into an intricate web with the quartz constituent.

Talc schist. — A schist made up largely of talc, but with varying proportions of quartz, magnetite, etc. From the abundance of the talc it is usually pale green or white.

Chlorite schist. — A greenish, fine-grained metamorphic rock in which chlorite is the principal mineral, but in which magnetite is a quite characteristic accessory constituent.

Staurolitic garnetiferous mica schist. — A mica schist in which garnet and staurolite are so abundant as to be essential constituents.

Clay slate. — A metamorphosed mud stone or shale. In the process of metamorphism the rock has been hardened, given a slaty cleavage, and innumerable minute scales of mica have developed to produce a silky luster upon the cleavage faces. The color may be gray, green, purple, or black.

Quartzite. — A metamorphosed sandstone in which the sand grains have become enlarged by accretion of silica. Whereas a sandstone fractures about its constituent grains, a break in quartzite is continued through the grains and the cement alike. In contrast to sandstones, the quartzites derived from them are usually lighter in color and often nearly white.

Marble (crystalline limestone). — The result of metamorphism upon limestones. Usually white in color but sometimes gray, blue gray, or yellow, and sometimes variously broken or brecciated and stained with iron oxide. Effervesces with cold dilute acid.

Coals. — Under the head of peat the first stage in the formation of coals from vegetable matter has been briefly described. Lignite, or brown coal, represents a further stage and one in which the vegetable structure is still recognizable. It is usually brownish black or black in color and contains a considerable proportion of water. With increased pressure or dynamic metamorphism, further percentages of the volatile constituents are eliminated, and when from seventy-five to ninety per cent of carbon remains, the material burns with a yellow flame and is known as bituminous coal. This is the great fuel for the production of steam. A continuation of the metamorphic processes carries off a further proportion of the volatile matter and leaves a dense, hard, black substance with sometimes as much as ninety-five per cent of carbon. This is the so-called "hard coal" or anthracite generally used for fuel in our houses, for which purpose it is so well adapted because it burns with a production of much heat and almost without smoke.

APPENDIX C

THE PREPARATION OF TOPOGRAPHICAL MAPS

Topographical maps a library of physiography. — For the satisfactory working out in detail of the geology of any region of complex structure, an accurate topographical map is prerequisite. This is so much the more true because nearly all complexly folded or faulted rock masses are to be found in mountainous, or at least in hilly regions. The making of the topographical map must, therefore, precede that of the geological map, and in modern usage the latter is a topographical and a geological map combined in one.

Within certain narrow limits, predictions concerning the geological history of a province may often be made by an expert geologist from examination of an accurate topographical map. Just as in forecasting the weather upon the basis of the usual weather maps, such predictions can sometimes be made with entire confidence in their accuracy, while at other times a guess only may be hazarded. The great value of the modern topographical map is becoming, however, universally acknowledged, and every highly civilized nation has either completed or has in preparation sectional topographical maps of its domain on such a scale as is warranted by its financial condition and its state of development. Thus there is now being accumulated a vast library of geographical and to some extent geological information, of which the student of geology must be prepared to make use.

The nature of a contour map. — More and more the contour map is replacing the earlier and less scientific methods of representing topography on the large scale sectional maps, and hence this type only need here be considered. In the contour map, the relief of the land is represented by a series of curving lines, each the intersection of a particular horizontal plane with the land surface, and the several planes separated by uniform differences of elevation. This altitude interval is known as the contour interval. Its choice is a matter of considerable importance, for though regions of relatively simple topography may be adequately represented upon a map of large contour interval, say one hundred feet, another district may require an interval as short as five feet. A contour map with this interval may be conceived to have been made by flooding

the region which it represents and preparing maps of the shore lines for each rise of five feet of the water surface, and superimposing the several maps thus derived with accurate registration one above the other. Wherever the land slopes are steep, the shore lines of the several maps will be crowded closely together and give the effect of a relatively dark local shade; where, upon the other hand, the surface is relatively flat, the several shores will be widely spaced and the effect will be to produce a white area upon the map. Thus in contour maps dark tones indicate steep gradients and pale tones a flatness of surface.

The selection of scale and contour interval. — With the use of the small scale in the contour map, the tones of the map will be correspondingly dark, though the relative differences in tone will remain the same. With the use of a closer contour interval the tones will deepen throughout. The adjustment of scale and contour interval to any given region is a matter requiring experience in topographical mapping, and in addition a knowledge of the geological significance of topographic features. Unfortunately, the element of expense and the special commercial objects held in view, conspire to select scales and contour intervals which are often little adapted to the districts surveyed.

The method of preparing a topographical map. — Having fixed upon the scale and the contour interval which is to be employed, the task of the topographical surveyor is next to fix accurately the positions and the elevations of a sufficient number of points to *control* the map, and then to hang, as it were, upon these points as attachments the design represented by the relief. Were the surface of the ground to be represented by a flexible fabric, the map maker might raise from a flat base a series of stout posts of the heights and in the positions which he has determined, and upon these supports arrange the slopes of the fabric much as drapery is adjusted. The determination of the exact positions and the elevations of his control stations is, therefore, a process coldly precise and formal; whereas in the shaping of the surfaces his attention should be fixed more upon correctly reproducing the shapes than upon fixing accurately the position of every point. As a matter of fact, the position of the average point will be most accurately fixed when the shapes of the features are most clearly comprehended. To some extent, therefore, the topographer should be familiar with the geological significance of the earth features which he is representing.

Laboratory exercises in the preparation of topographical maps. — The principles which underlie the surveyor's method for preparing a topographical map may be learned in the laboratory by the use of models and the simple device shown in plate 24 A and B. To represent the section of country to be mapped a model in plaster of Paris is substituted, and this

is placed within a rectangular tank to which locating carriages and altitude gauges are attached that allow the student to fix the position and the elevation of any point upon the surface of the model.

Upon each model the student "locates," or fixes, the position of a sufficient number of points for the control of his map, entering upon an appropriate map base for each position the altitude which was read from the gauges. Now *with the map always before him* he "sketches in" the forms of the surface by means of contour lines. For this purpose it is often desirable to fix roughly the direction of the steepest slope at a

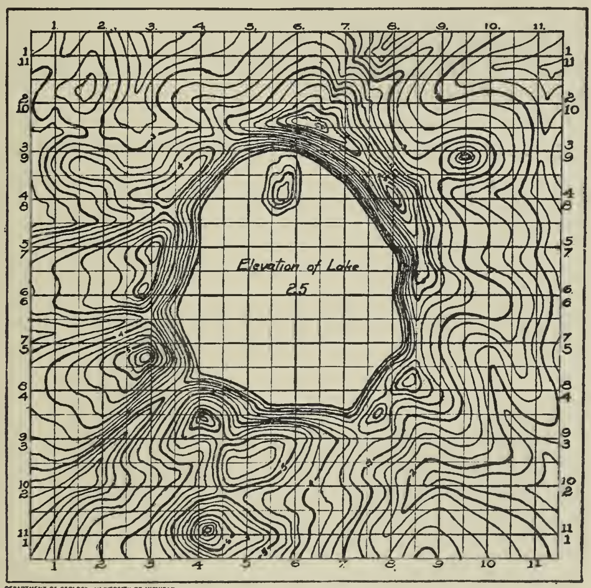
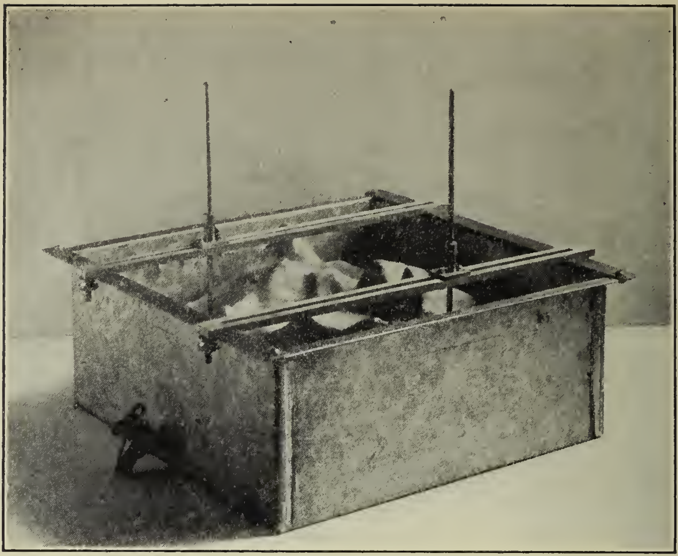


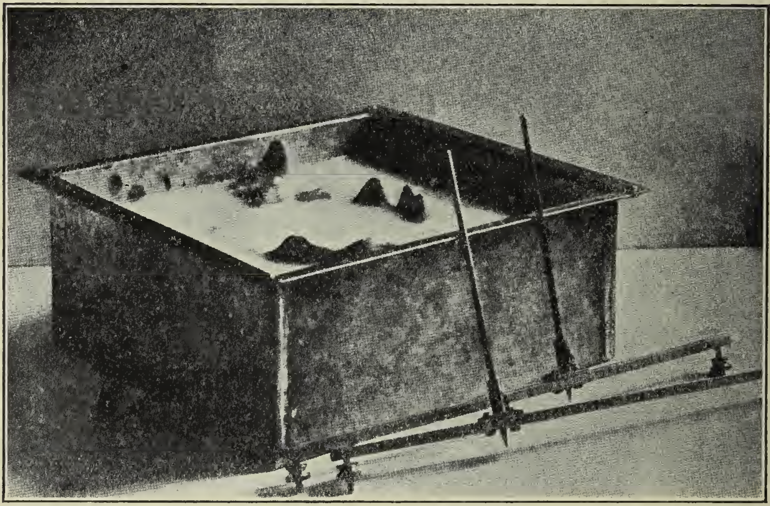
FIG. 488. — A student's map prepared from a model by the use of the contour apparatus represented in plate 24 A.

number of places, and noting the differences in elevation between control stations, divide up the distance in accordance with the curves of slope and start the contours at right angles to the slope. Afterwards such sections are connected by sketching in with the model always in view for control (Fig. 488).

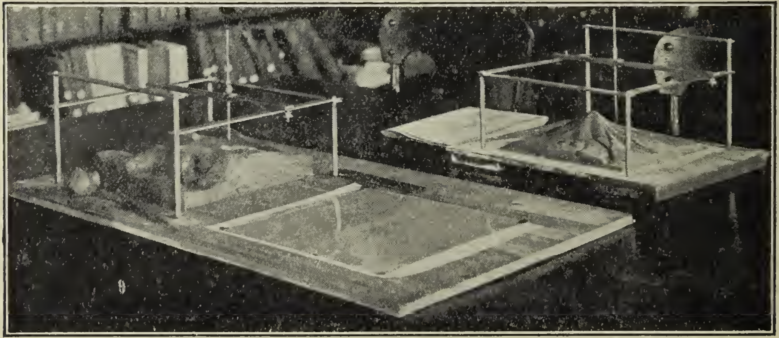
The verification of the map. — The map prepared, its accuracy may be tested by a simple method which is denied the topographer who has to do with the actual surface of the ground. The locating carriages and altitude gauges are removed from the tank, which is next filled with



A. Apparatus for exercise in the preparation of topographic maps.



B. The same apparatus in use for testing the contours of a map.



C. Modeling apparatus in use.

water and leveled by means of guide marks upon the interior. A few drops of milk or of ordinary clothes blueing are added to the water to render it opaque, and it is then drawn off at the faucet in successive installments, so that the surface drops by layers corresponding in thickness to the contour interval of the map, plate 24 B. As each layer is withdrawn, that contour of the map to which the shore line should correspond is carefully examined and corrected. By such corrections the nature of the first errors made is soon appreciated, and the method of procedure is thus more easily acquired. At the same time the significance of the design of the map is more quickly learned than by a mere examination of the standard government maps.

The work above outlined calls for waterproofed models of suitable form and size, and a series, each of which sets forth some typical feature or series of features, has been designed by Mr. Irving D. Scott.[1]

The preparation of physiographic models. — The apparatus used to prepare the topographic map is adapted also for preparing a physiographic model from a standard topographical map. For this purpose the method is essentially reversed, though the tank is replaced to advantage by a light metal frame elevated upon one side so as to permit a free use of the hands in modeling the clay.

The material used in preparing the model is artists' modeling clay[2] which has a base of beef suet, and hence does not dry out and crack as does ordinary clay. Its form is, therefore, retained indefinitely, and it may be used again and again. Most maps must be enlarged in modeling, and the simplest way is often to photographically or by pantograph enlarge the map to the scale of the model. The map prepared, it is covered by a thin celluloid plate which has cut upon it a series of crossed lines spaced in inches and larger subdivisions to correspond to those of the locating carriages (plate 24 C).

The enlargement of the map is not essential to experienced workers, and the standard map may be covered in similar manner by a transparent plate with " checkerboard " design, the squares of which bear some simple relation in size to the larger divisions of the locating carriages (Plate 24 C, rear).

The method of preparing the model is comparatively simple. Beginning at any point upon the map, the intersection of a heavy contour line with one of the guide lines of the celluloid " position plate " is carefully noted. Both the position and the elevation of this point are fixed by the point of the altitude gauge of the modeling frame, and the clay built

[1] These models and the contouring apparatus are now manufactured for the use of schools and colleges by Eberbach and Son, Ann Arbor, Mich.

[2] This clay is manufactured by the A. H. Abbott Company, art dealers, Wabash Avenue, Chicago.

up beneath it to that height. With the fingers the clay is now roughly shaped in various directions from this point, the altitude gauge is advanced by the locating carriage so as to correspond in position to the intersection of the next heavy contour line with the same guide line of the position plate, and the elevation for this point similarly adjusted upon the model. As before, the surface of the clay is roughly shaped in advance and upon the sides so as to conform to the indications of the map; and this process is repeated until the work is finished. Corrections for intermediate positions may be carried to any desired degree of refinement which the scale and the accuracy of the map permit. Models which are larger than the area of the modeling frame are prepared by making a square foot at a time by the above described process, and then moving the frame forward and adjusting in a new position by means of the sharp pins in the legs of the apparatus.

LABORATORY STUDY IN THE PREPARATION AND INTERPRETATION OF GEOLOGICAL MAPS

The field map and the areal geological map. — As the atlas of topographic maps is the physiographic gazetteer, so geological maps together constitute the reference dictionary of descriptive geology. Not only are topographic maps of many districts now generally available, but more and more it has become the policy of governments to supply geological maps in the same quadrangle form which is the unit of the topographic map. The geological map is, however, a complex of so many conventional symbols, that without some practical experience in the actual preparation of one, it is exceedingly difficult for the student to comprehend its significance. A modern geological map is usually a rectangular sheet printed in color, upon which are many irregular areas of individual hue joined to each other like the parts of a child's picture puzzle.

The colored areas upon the geological map are each supposed to indicate where a certain rock type or formation lies immediately below the surface, and this distribution represents the best judgment of the geologist who, after a study of the district, has prepared the map. Unfortunately the conventions in use are such that his observation and his theory have been hopelessly intermingled in the finished product. Armed with the geological map, the student who visits the district finds spread out before him, it may be, a landscape of hill and valley, of green forest and brown farming land, which is as different as may be from the colored puzzle which he holds in his hand. Hidden under the farm vegetation

or masked by the woods are scattered outcroppings of rock which have been the basis of the geologist's judgment in preparing the map. Experience shows that in order to bridge the wide gap between the geology in the landscape and the patches of color upon the map something more than mere examination of the colored sheet is necessary. We shall therefore describe, with the aid of laboratory models, the various stages necessary to the preparation of a geological map, and every student should be advised to follow this by practical study of some small area where rocks are found in outcrop.

Though the published *areal geological map* represents both fact and theory, the map maker retains an unpublished *field map* or map of observations, upon which the final map has been based. This field map shows the location of each outcrop that has been studied, with a record of the kind of rock and of such observations as strike, dip, and pitch. Our task will therefore be to prepare: (1) a field map; (2) an areal geological map; and (3) some typical geological sections.

Laboratory models for the study of geological maps. — In order to represent in the laboratory the disposition of rock outcrops in the field, special laboratory tables are prepared with removable covers and with fixed tops which are divided into squares numbered like the township sections of the national domain (Fig. 489). To represent the rock outcrops, blocks are prepared which may be fixed in any desired position by fitting a pin into a small auger hole bored through the table. The outcrop blocks for the sedimentary rock types are so constructed as to show the strike and dip of the beds (p. 29, figs. 491, 492).

The method of preparing the map. — To prepare the map, use is made of a geological compass with clinometer attachment, a protractor, and

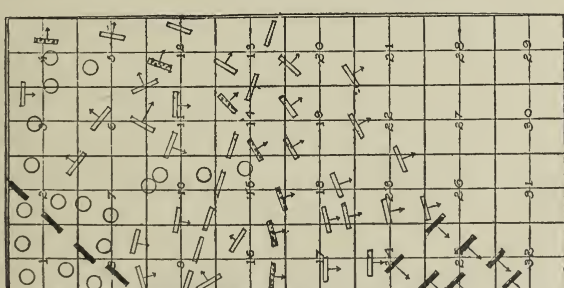


FIG. 489. — Field map prepared from a laboratory table.

a map base divided into sections like the top of the table, and on scale of, say, one inch to the foot. Each exposure represented upon the table is "visited" and then located upon the base map in its proper position

and attitude. The result is the field map (Fig. 489), which thus represents the facts only, unless there have been uncertainties in the correlation of exposures or in determining the position of the bedding plane.

To prepare the areal geological map from the field map, it is first necessary to fix the *boundaries* which separate formations at the surface; and

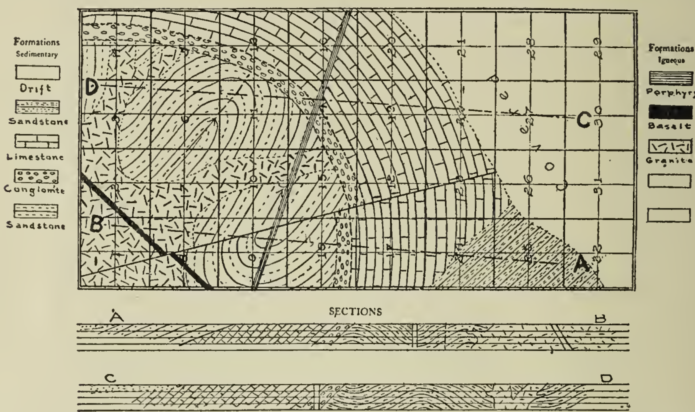


Fig. 490. — Areal geological map constructed from the field map of Fig. 489, with two selected geological sections.

now perhaps for the first time it is realized how large an element of uncertainty may enter if the exposures were widely separated. It is clear that no two persons will draw these lines in the same positions throughout, though certain portions of them — where the facts are more nearly adequate — may correspond. In Fig. 490 is represented the areal geological map constructed from the field map, with the doubtful area at one side left blank.

Some conclusions from this map may now be profitably considered. The complexly folded sandstone formation at the left of the map appears as the oldest member represented, since its area has been cut through by the intrusive granite which does not intrude other formations, and is unconformably overlaid by the limestone and its basal layer of conglomerate. The limestone in turn is unconformably overlaid by the merely tilted sandstone beds at the right of the map. These three sedimentary formations clearly represent decreasing amounts of close folding, from which it is clear that each earlier formation has passed through an episode not shared by that of next younger age. Of the other intrusive rocks, the dike of porphyry is younger than all the other formations, with the possible exception of the upper sandstone. Offsetting of the formations has disclosed the course of a fault, and from its relations

to the dikes we may learn that of these the porphyry is younger and the basalt older than the date of the faulting.

The dashed lines upon the map (*AB* and *CD*) have been selected as appropriate lines along which to construct geological sections (Fig. 490 below map), and from these sections the *exposed* thicknesses of the different formations may be calculated. In one instance only, that of the conglomerate, can we be sure that this exposed thickness measures the entire formation.

The laboratory models which represent the outcrops[1] are shown in Fig. 491. The drumshaped blocks serve to represent massive rocks which occur in irregularly shaped masses such as batholites and flows. The long, narrow strips are for intrusive rocks in the form of dikes, while the larger blocks provided with a swivel joint are used for outcrops of sedimentary rocks, and after adjustment they give the dip and strike of the exposure. The wing bolts used in their construction should be of bronze, because of the effect of iron upon the compass. For the same reason tables should not be placed near iron beams or columns. With a view to supplying suggestions for other problems of the same general nature as the one shown in Fig. 489, the three additional field maps of Fig. 493 have been introduced.

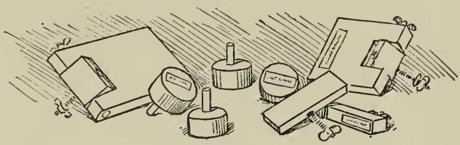


Fig. 491. — Models to represent outcrops of rock.

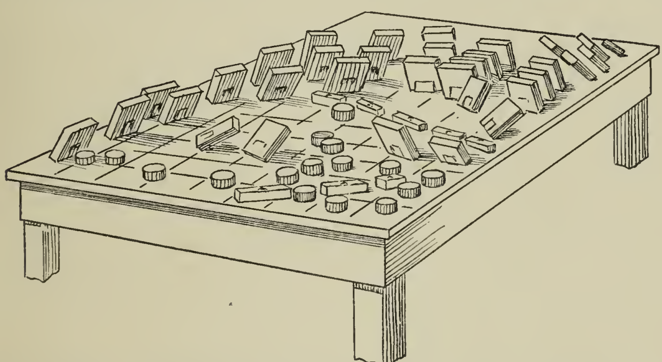


Fig. 492. —Special laboratory table set with a problem in geological mapping which is solved in Figs. 489 and 490.

[1] A simplified type of model and tabular base to place over ordinary laboratory tables is now manufactured by Eberbach & Son, Ann Arbor, Mich.

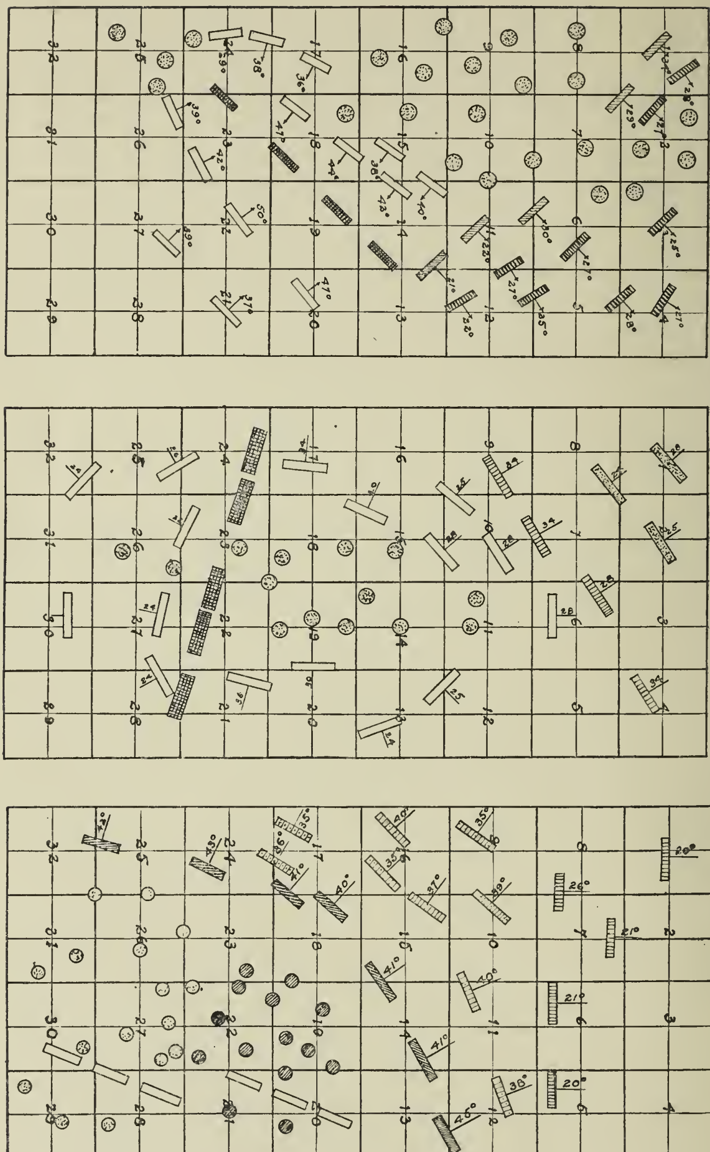


FIG. 493.—Three field maps to be used as suggestions in arranging laboratory tables for problems in the preparation of areal geological maps.

The list of questions given below is intended to indicate the nature of some of the problems which the student should be asked to solve in the preparation of each map. The numbers in parentheses refer to pages in the author's "Earth Features," where further information is given: —

Stratigraphical

1. Of the formations represented what ones are sedimentary and what igneous (Chap. IV)?
2. Which formations, if any, are separated by unconformities (51–53)?
3. What is the order of age of the sedimentary formations (65)?
4. What are the *exposed* thicknesses of each of these formations (48–49)?
5. Do any of these values represent full thickness of the formation, and if so, which ones?
6. What is the age in terms of the sedimentary formations of each of the igneous rock masses (65)?
7. Which igneous rocks, if any, occur in batholites (143, 441)? Which, if any, in dikes (140)?

Structural

8. What formations, if any, have monoclinal dip (42)?
9. Indicate upon the map by dashed lines the crests of all anticlines and the trough lines of synclines.
10. Indicate by arrows the direction of pitch of all plunging anticlines and synclines wherever disclosed by changes of dip and strike (43).
11. Indicate the approximate position of all faults whose position is disclosed (58–61), and if possible, state which limb is the one downthrown.
12. Prepare suitable geological sections.

Reading Reference

William H. Hobbs. Apparatus for Instruction in Geography and Structural Geology. The Interpretation of Geologic Maps. School Science and Mathematics, vol. 9, 1909, pp. 644–653.